Indian J. Phys. **69A** (6), 649–656 (1995)

NOTE

IJP A
- an international journal

Multiparticle production and pseudorapidity distribution in high energy hadron-nucleus collisions

S K Bhattacharjee* and G C Deka
Nuclear Research Centre, Department of Physics, Cotton College,
Guwahati-781 001, Assam, India

Received 3 May 1995, accepted 14 August 1995

Abstract : Multiparticle production mechanism in hadron-nucleus collisions is studied by analysing a quantity $\eta = -\ln \tan \theta/2$, called pseudorapidity of the produced particle, where θ is the laboratory angle of emission in this study, a few pellicles of nuclear photographic emulsion exposed to 50 GeV/c negative pions, 70 GeV/c proton and 200 GeV/c proton beam are used. It is found that mean values of η shift towards lower rapidity region with increase of effective sizes of the target mass. Again it is found that η-distribution in projectile fragmentation region is independent of the size of the target nucleus. Also the dispersion of η-distribution is found to be independent of the target size. Thus, the present study disagrees with the predictions of multiperipheral class of models and coherent tube model but broadly agrees with energy flux cascade model, two phase model and superposition model which belong to double step mechanism class of models

Keywords : Hadron-nucleus collision, multiparticle production, pseudorapidity

PACS No. : 13.85.-t

The mechanism of multiparticle production in hadron-nucleus (hA) collisions may be described as given below :

(a) In a hA collision, the first hadron-nucleon (hN) collision acts as a trigger.

(b) In the first hN collision, the particles are produced according to the production mechanism as viewed in multiperipheral model [1] and its Regge-generalisation, bremsstrahlung model [2], hydrodynamical model [3], fragmentation model [4] *etc*.

(c) If the first hN collision is described by multiperipheral or bremsstrahlung process, then the particles are created directly or in a single step. These particles become physical within the nucleus and intra-nuclear cascading proceeds within the nucleus.

*Present address : Department of Physics, Darrang College, Tezpur-784 001, Assam, India

(d) On the otherhand, if hN collisions are described by double step mechanism class of models, such as hydrodynamical model, fragmentation model *etc.* then the particles created in the first hN collision do not become physical within the nucleus due to relativistic dilation of interaction time. Hence, two-particle successive collisions by each particle resulted from the first hN collision with the down stream nucleons is not possible.

(e) In a hA collision, it is the energy flux of hadronic matter [5] or an excited phase [6] or a fast excited state [7] or a fragment of projectile or a cluster of particles that develops a cascade of interactions with the down stream nucleons producing slow energy flux [5] or slow excited states [7] or slow hadronic matter which along with initial excited hadronic matter decays into final state particles outside the nucleus.

(f) In a hA collision, the incident hadronic matter may also interact coherently with down stream nucleons cutting a tunnel [8] through the nuclear matter. In the first step of collision, an intermediate state of excitation is developed in a very small volume which in the second step of collision expands, cools down and the final state particles become physical outside the nucleus.

(g) The hA collision may also be described by superposition model [9] in which the main parameter governing the particle production is tne number of individual nucleon-nucleon collisions.

In an inclusive hA interaction, a quantity

$$Y = \left(\frac{1}{2}\right) \ln \left[(E+P_L)/(E-P_L)\right]$$

is called longitudinal rapidity of the produced particle. If θ be the angle of emission and $P_T > m$, then another quantity

$$\eta = -\ln \tan \theta/2,$$

is defined as pseudorapidity of the particle which approximates longitudinal rapidity. Here, E, P_L, P_T and m refer respectively to energy, longitudinal and transverse components of momentum and mass of the produced particles which are mostly pions.

Since the prediction regarding rapidity distribution is different according to different models, the study of rapidity distribution is useful for understanding the production mechanism of particles. Many authors [10,11,12] have studied such distributions at different energies. In the present report η-distributions of the particles produced in hadron-emulsion nuclei collisions is studied at 50, 70 and 200 GeV/c energies.

Ten pellicles of NIKFI BR-4 each (10 × 20) sq cm × 600 μm exposed to 50 GeV/c π^-, ten pellicles of NIKFI BR-2 and four pellicles of NIKFI BR-3 each of dimension (10 × 20) sq cm × 600 μm and (10 × 20) sq cm × 400 μm respectively exposed to 70 GeV/c proton beam of the Institute of High Energy Physics, Serpukhov, Russia and two pellicles of Ilford G5 emulsion of dimension (10 × 12) sq cm × 600 μm each irradiated by 200 GeV/c proton beam at FNAL, USA are used for investigation.

All emulsion plates are area scanned by using ASCO microscope and interaction stars lying at a depth 10 μm from the top and bottom surfaces are recorded. For the detection of primary beam shower tracks formed by produced particles are observed through Cooke, Throughton and Simns microscope using 15 × eyepiece and 95 × oil objective. The angular resolution of highly collimated and overlapping shower tracks are made by taking observations on projected angles at a distance 500 μm to 1000 μm from the centre of the star. Measurements of dip angles are made by taking observations on Z-coordinate at origin of the star and at a point 500 μm away from the star. Space angle of a shower track with respect to primary beam is obtained from the measurement of projected angle and dip angle.

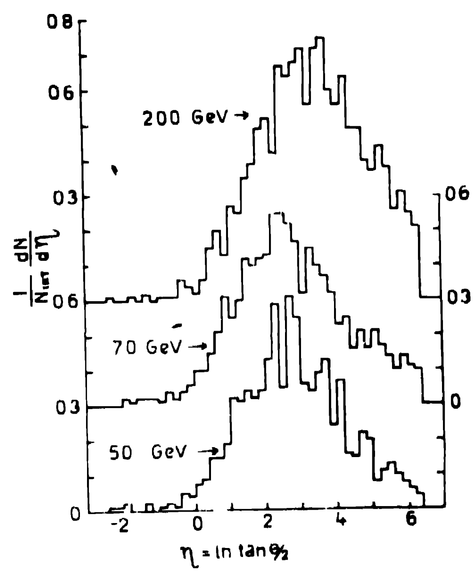

Figure 1. Pseudorapidity distributions (normalised to one interaction) of shower particles produced in hadron-emulsion collisions at 50, 70 and 200 GeV/c.

Dependence of η-distribution on incident energy of beam particles is studied at three incident energies. Figure 1 shows the number of charged secondary particles produced per interaction against rapidity η at 50, 70 and 200 GeV/c. From Table 1 it is observed that the mean values of η increase slowly with increase of energy indicating a weak energy dependence of η in the energy range 50 to 200 GeV/c.

Target mass dependence of η-distribution is studied by classifying the data according to the size of the interaction stars *i.e.*, according to the number of heavily ionising racks, N_h ; because the effective mass of the target nucleus is dependent on the impact parameter or the centrality of the interactions. Again the effective size of the target nucleus s related to $< \nu >$, the average number of successive collisions with the nucleons of the nucleus or the average number of nucleons in the nuclear tube colliding simultaneously with the incident hadron. Figures 2, 3 and 4 show η-distributions at 50, 70 and 200 GeV/c

Table 1. Mean values of pseudorapidity η and its dispersion D.

Incident energy Gev/c		$3 < N_h < 7$	$6 < N_h < 17$	$N_h > 16$
η	50	3.26 ± 0.12	2.85 ± 0.05	2.40 ± 0.05
D		1.52 ± 0.08	1.40 ± 0.04	1.40 ± 0.04
η	70	3.30 ± 0.11	2.69 ± 0.06	2.28 ± 0.07
D		1.55 ± 0.08	1.54 ± 0.04	1.47 ± 0.06
η	200	3.67 ± 0.12	3.32 ± 0.06	3.14 ± 0.07
D		1.35 ± 0.07	1.44 ± 0.04	1.59 ± 0.05

respectively, each being classified according to the sizes of the interaction stars. In these plots, 2513 showers from 279 stars, 1784 showers from 181 stars and 1072 showers from

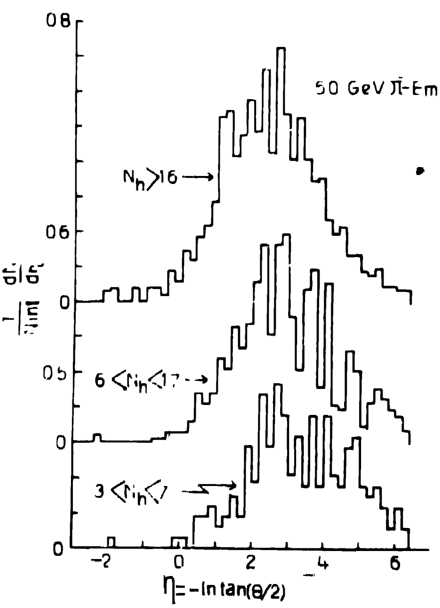

Figure 2. Pseudorapidity distributions (normalised to one interaction) of shower particles produced in π^--emulsion nuclei collisions at 50 GeV/c for different N_h intervals.

83 stars are plotted at 50, 70 and 200 GeV/c respectively. Events having $6 < N_h < 17$ refer to peripheral collisions with AgBr nuclei. Events having $N_h > 16$ refer to central collisions with nuclei. Events with $N_h < 7$ refer to interactions with CNO group of nuclei. This last group also includes highly peripheral collisions with AgBr nuclei. Table 2 shows the interaction characteristics of events of such sub-groups at different incident energies. It is

observed from this table that the average charged particle multiplicity $< n_s >$, increases sharply with increase of $< N_g >$ or $< N_h >$ at each incident energy. It indicates that the

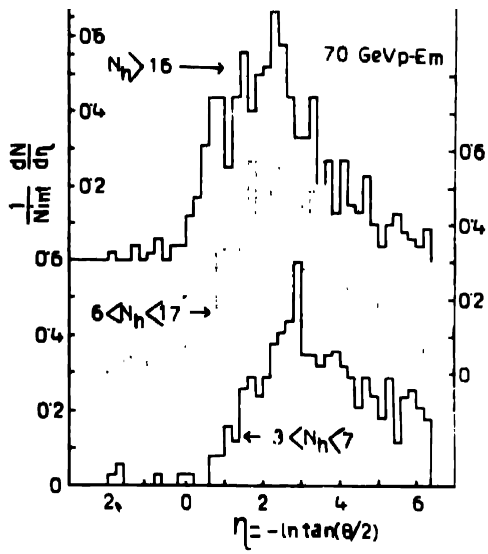

Figure 3. Pesudorapidity distributions (normalised to one interaction) of shower particles produced in proton-emulsion nuclei collisions at 70 GeV/c for different N_h groups of interactions

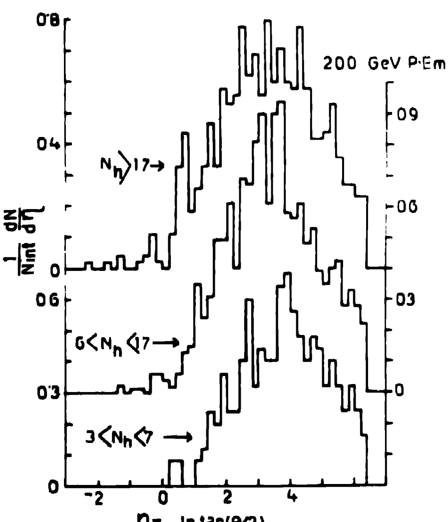

Figure 4. Pseudorapidity distributions (normalised to one interaction) of shower particles produced in proton-emulsion nuclei collisions at 200 GeV/c for different N_h groups of interactions.

multiplicity of produced particles depends on average number of grey tracks formed by the recoil protons or the average number of heavy tracks formed by the particles evaporated from the excited struck nucleus. The mean number of successive collisions of the incident hadrons or the mean number of energy flux of hadronic matter [5] or the mean number of

Table 2. Characteristics of interactions at different energies.

Incident energy GeV/c	Interaction characteristics	$3 < N_h < 7$ $<\nu> = 1.34$	$6 < N_h < 17$ $<\nu> = 3.87$	$N_h > 16$ $<\nu> = 4.62$
50	$<N_g>$	0.67 ± 0.11	2.07 ± 0.11	4.66 ± 0.23
	$<N_h>$	4.63 ± 0.28	11.26 ± 0.25	21.74 ± 0.49
	$<n_s>$	6.88 ± 0.35	8.18 ± 0.22	10.65 ± 0.34
70	$<N_g>$	1.22 ± 0.18	2.64 ± 0.17	4.73 ± 0.28
	$<N_h>$	4.80 ± 0.34	10.72 ± 0.35	21.46 ± 0.60
	$<n_s>$	8.10 ± 0.45	9.86 ± 0.34	13.01 ± 0.47
200	$<N_g>$	0.85 ± 0.16	3.15 ± 0.19	5.79 ± 0.33
	$<N_h>$	3.97 ± 0.34	10.11 ± 0.34	21.89 ± 0.64
	$<n_s>$	9.27 ± 0.52	12.73 ± 0.38	14.62 ± 0.53

Table 3. Variation of $<\eta>$ with $<\nu>$, mean number of collisions within a nucleus at different incident energies

$<\nu>$	$<\eta>$ 50–70 GeV/c	$<\eta>$ 200 GeV/c
1.34	3.28 ± 0.11	3.67 ± 0.12
3.87	2.77 ± 0.05	3.32 ± 0.06
4.62	2.34 ± 0.06	3.14 ± 0.07

excited phase [6] interacting with the down stream nucleons of the struck nucleus expressed as $<\nu>$, is found to be related to $<N_g>$ or $<N_h>$. For three groups of interactions the values of $<\nu>$ are calculated as it was done in Ref. [13]. Table 3 shows the variation of $<\eta>$, the pseudorapidity of the produced particles with $<\nu>$.

The conclusion of our study is given below :

(i) It is found that the distribution of particles are not equally spaced in rapidity η.

(ii) It is found that the mean values of η shift gradually towards lower rapidity region as N_h values of the interaction sub groups increase.

(iii) It is observed that with increase of incident energy η-distribution spreads towards higher values of η.

(iv) It is also found that η-distribution in projectile fragmentation region (corresponding to higher values of η) is independent of the size of the interaction stars *i.e.* effective mass of the target nucleus.

(v) **Dispersion, D of η-distribution** is almost uniform among the different interacung subgroups.

(vi) Mean values of η decrease with increase of $< \nu >$, mean number of collisions with nucleons of the nucleus.

According to multiperipheral and other single step mechanism class of models, the produced particles should be equally spaced in rapidity and η-distribution should be flat. But such distinct flat parts are not observed in our study of rapidity spectra. Our observations disagree with predictions of multiperipheral model but agree with the predictions of fragmentation model.

According to coherent tube model, the rapidity spectra in hA collisions are identical to those in hN collisions and dispersion, D should increase with increase of $< \nu >$ or with increase of N_h values of different interacting sub-groups. But in our observation, D is independent of the size of the stars and independent of $< \nu >$. Thus, our observation contradicts with the prediction of coherent tube model.

Most of the excess of the particles with increasing $< \nu >$ or with increasing N_h sub-groups appear in the backward rapidity region which broadly agree with Gottfried's model [5], Fishbane and Trefil's model [6] and superposition model [9] which belong to 'double step mechanism' class of models for hN collisions.

Acknowledgments

The authors express their gratitude to Prof. K D Tolstov of JINR Dubna, Russia for his lending of the developed emulsion plates of 50 GeV/c negative pion and 70 GeV/c proton and to late Prof. P K Malhotra of TIFR, Bombay for providing them with 200 GeV/c proton plates. They are also thankful to the scanners of the research centre for their help in doing this piece of work. Thanks are also due to the Head of the Department of Physics, Cotton College, Guwahati for his encouragement in this work.

References

[1] D Amati, A Stranghellini and S Fubini *Nuovo. Cim.* **26** 896 (1962)

[2] R P Feynman *Phys Rev. Lett.* **23** 1415 (1969)

[3] L D Landau *Sov. J Nucl. Phys.* **92** 535 (1953)

[4] J Benecke, T T Chou, C N Yang and E Yen *Phys. Rev* **188** 2159 (1969)

[5] K Gottfried *Phys. Rev. Lett.* **32** 957 (1974)

[6] P M Fishbane and J S Trefil *Phys. Lett.* **51B** 139 (1974)

[7] A Dar and J Vary *Phys. Rev.* **D6** 2412 (1972)

[8] S Z Belenkji and L D Landau *Suppl. Nuovo. Cim.* **3** 15 (1956)

[9] K Werner *Phys. Rev.* **D39** 780 (1989); B Anderson, G Gastafson and B Nilsson-Almqvist *Nucl. Phys.* **B281** 289 (1987)

[10] A Mazumder, D P Goyal, P K Sen Gupta and S Singh *Can. J. Phys.* **58** 972 (1980)

[11] V Kumar, S C Verma, N S Verma and A P Sharma *Pramana-J. Phys.* **2** 479 (1978)

[12] D K Bhattacharjee, S Naha and T Roy *Indian J. Pure Appl. Phys.* **18** 579 (1980)

[13] S K Bhattacharjee and G C Deka *Indian J. Phys.* **68A** 507 (1994)